REVIEW

Endodontic implications of the maxillary sinus: a review

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Abstract

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The anatomical and clinical significance of the maxillary sinus in relation to conventional and surgical endodontic therapy is considered. The discussion includes a review on the development, anatomy and physiology of the maxillary sinus, the diagnostic evaluation of the sinus and the differential diagnosis of sinusitis. Endodontic implications of the maxillary sinus include extension of periapical infections into the sinus, the introduction of endodontic instruments and materials beyond the apices of teeth in close proximity to the sinus and the risks and complications associated with endodontic surgery.

Keywords: endodontics, maxillary sinus, periapical infection, New Zealand.

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Introduction

The anatomical and clinical significance of the maxillary sinus was first described by Nathaniel Highmore (Highmore 1651) in 1651 with a report on the drainage of an infected sinus through the extraction socket of a canine tooth. Since that report, the maxillary sinus or antrum of Highmore has played an important part in the dental treatment of maxillary teeth.

The dental literature contains many references to the extension of periapical inflammation to the maxillary sinus (Bauer 1943, Selden & August 1970, Selden 1974, Selden 1989, Selden 1999). Stafne (1985) estimated that 15–75% of the time, sinusitis occurs through a dental cause although the true incidence is difficult to determine accurately. Ingle (1965) believed that contact between the maxillary sinus floor and inflammatory lesions resulted in the development of chronic sinusitis. It is also accepted that symptoms of maxillary sinusitis can emulate pain of dental origin, and a careful differential diagnosis is thus essential when dealing with pain in the maxillary posterior area (Schwartz & Cohen 1992).

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Development, anatomy and physiology of the maxillary sinus

The maxillary sinus is the first of the paranasal sinuses to develop in human foetal life. During the fifth foetal month, secondary pneumatization starts as the maxillary sinus grows beyond the nasal capsule into the maxilla (Koch 1930). At birth, the sinus is approximately $10 \times 3 \times 4$ mm in dimension and continues to grow slowly until the age of 7 years when expansion occurs more rapidly until all the permanent teeth have erupted. The average dimensions of the maxillary sinus of the adult are $40 \times 26 \times 28$ mm with an average volume of 15 mL (Bailey 1998, Sadler 1995).

The maxillary sinus is typically pyramidal in shape with the base of the pyramid forming the lateral nasal wall and the apex extending into the zygoma (Bailey 1998). The roof of the sinus, which also forms the floor of the orbit, is composed of thin bone with the infraorbital neurovascular bundle found in the central portion of the bone. This nerve is dehiscent in 14% of the population and may be damaged during manipulation in this area (Donald *et al.* 1995). The anterior wall corresponds to

the canine fossa of the anterior maxilla. The posterior wall separates the sinus from the contents of the infratemporal and pterygomaxillary fossae. The floor of the sinus is formed by the alveolar process of the maxilla and partially by the hard palate. Whilst it lies 4 mm above the floor of the nasal cavity in children, it ultimately lies 4–5 mm below the floor of the nasal cavity in adults (Bailey 1998). The adult sinus is variable in its extension. In about 50% of the population, it may expand into the alveolar process of the maxilla, forming an alveolar recess. In these cases the maxillary sinus comes in close relation to the roots of the maxillary molar and premolar teeth, particularly the second premolar and the first and second permanent molars. In rare cases the sinus floor can extend as far as the region of the canine root (Schuh *et al.* 1984). The sinus floor exhibits recesses extending between adjacent teeth or between individual roots of teeth. The alveolar bone can become thinner with increasing age, particularly in the areas surrounding the apices of teeth, so that root tips projecting into the sinus are covered only by an extremely thin (sometimes absent) bony lamella and the sinus membrane. The deepest point of the maxillary sinus is normally located in the region of the molar roots with the first and second molars the two most commonly dehiscent teeth in the maxillary sinus at 2.2% and 2.0%, respectively (Lang 1989). However, with extensive pneumatization, the third molar, premolars and canine teeth may all be exposed into the sinus (Bailey 1998). This places the neurovascular bundle of the teeth in danger during curettage of the sinus. Furthermore, the extraction of teeth owing to apical pathology may result in an oroantral communication or fistula (Bailey 1998). In response to reduced function associated with the loss of posterior teeth the sinus may expand further into the alveolar bone, occasionally extending to the alveolar ridge (White & Pharoah 2000).

The medial wall of the maxillary sinus or lateral wall of the nose contains the sinus ostium, which opens into the middle meatus of the nose and provides essential drainage. The ostium lies approximately two thirds up the medial wall of the sinus, anatomically making drainage of the sinus inherently difficult. In 15% to 40% of cases a very small, accessory ostium is also found (Bailey 1998). Blockage of the ostium can easily occur when swelling or thickening of the mucosal lining of the ostium develops.

The maxillary sinus is supplied by branches of the maxillary and facial arteries, partly by endosseous vessels, partly by periosteal vessels (Watzek *et al.* 1997). Periosteal supply is provided by the sinus membrane which in turn, is supplied by the posterior–superior dental artery or by the infraorbital artery (buccally) and the palatine artery (palatally). Venous drainage occurs via the facial vein, the sphenopalatine vein and the pterygoid plexus. The significance of the vascular drainage of the sinus lies in the fact that apart from joining typical pathways in the maxilla to the jugular veins, it can also drain upward into the ethmoidal and frontal sinuses and eventually reach the cavernous sinus in the floor of the brain. Spread of infection via this route is a serious complication of maxillary sinus infections.

The innervation of the sinus is of particular interest from a diagnostic standpoint. The nerve supply is from the maxillary division of the trigeminal nerve, with branches coming directly from the posterior, middle and anterior superior alveolar nerves, the infraorbital nerve and the anterior palatine nerve. The posterior wall of the sinus receives its nerve supply from the posterior and middle superior alveolar nerves, whilst the anterior wall is supplied by the anterior superior nerve (Watzek *et al.* 1997). These nerves travel enclosed in the wall of the sinus innervating the related teeth (Wallace 1996). It could, thus, be difficult to distinguish pain of dental origin from that of sinus origin. Also, a buccal surgical endodontic approach involving the sinus does not generally produce bleeding problems (Altonen 1975, Waite 1971) but it does involve the nerves and may induce paraesthesia (Wallace 1996).

The function of the paranasal sinuses remains largely unknown. Theories include roles such as: humidification and warming of inspired air, assisting in regulating intranasal pressure, increasing the surface area of the olfactory membrane, lightening the skull to maintain proper head balance, imparting resonance to the voice, absorption of shocks to the head, contributing to facial growth and lastly, exist as evolutionary remains of useless air spaces (Bailey 1998).

The pathophysiology of sinus disease is related to three factors: patency of the ostia, function of the cilia and the quality of the nasal secretions (Bailey 1998). These factors contribute to the adequate drainage of the sinus. Treatment of sinus disease is based on establishing and then maintaining adequate drainage.

The prime functional structure of the nasal fossa and paranasal sinuses is the mucosal lining. The mucosa of the paranasal sinuses is continuous with the nasal cavity and, although much thinner, is also composed of ciliated and nonciliated pseudostratified columnar epithelium interspersed with goblet cells. The goblet cells produce thick mucus in response to irritation (Bailey 1998). The ciliated and nonciliated columnar cells possess microvilli that are 1.5 μm in length and 0.08 μm in diameter (Petruson *et al.* 1984). The microvilli help expand the

surface area of the epithelium to improve humidification and warming of air (Petruson *et al.* 1984). Serous and mucinous glands are located under the basement membrane and produce thick and thin mucus in response to the autonomic nervous system (Bailey 1998). The cilia are essential to the maintenance of sinus health. They function in mass action, producing co-ordinated sequential beating, thus creating a wave-like motion, generally in the direction of the ostium. The mucus flows constantly, propelled by the underlying cilia. The film of mucus moves in a spiral direction upward, towards the ostium. A new mucinous blanket is formed every half hour. It is thus easy to understand how loss of cilia will interfere with elimination of the continuously forming mucus.

Diagnostic evaluation of the maxillary sinus

Radiographic examination of the maxillary sinus may be accomplished with a wide variety of exposures readily available in the dental surgery or radiology clinic (Peterson 1993). These include periapical, occlusal, panoramic and facial views, which may provide adequate information to either confirm or rule out pathology. On periapical radiographs, the borders of the maxillary sinus appear as a thin, delicate tenuous radiopaque line (actually a thin layer of cortical bone) (White & Pharoah 2000). In the absence of disease it appears continuous, but on close examination it can be seen to have small interruptions in its smoothness or density. In adults the sinuses are normally seen to extend from the distal aspect of the canine to the posterior wall of the maxilla above the tuberosity. The floors of the sinus and the nasal cavity are seen at approximately the same level at puberty. In older individuals the sinus floor may extend further into the alveolar process and may appear considerably below the level of the floor of the nasal cavity. Anteriorly each sinus is restricted by the canine fossa and is usually seen to sweep superiorly, crossing the level of the floor of the nasal cavity in the premolar or canine region. The roots of the molars usually lie in close apposition to the maxillary sinus. Root apices may project into the floor of the sinus, causing small elevations or prominences. The thin layer of bone covering the root is seen as a fusion of the lamina dura and the floor of the sinus (White & Pharoah 2000). A periapical radiograph may fail to show lamina dura covering the root apex in areas with defective bony covering.

Panoramic radiography provides an extensive overview of the sinus floor and its relationship with the tooth roots. It allows determination of the size of periapical lesions and cysts as well as radiodense foreign bodies. Matilla (1965) demonstrated that stereo-orthopantomography is a reliable mode of examination when distance between periapical lesions and the mucous membrane of the sinus, as well as interdistances of dental roots and the floor of the sinus have to be clarified. In orthopantomography the central radius goes almost straight toward the longitudinal axis of the molars resulting in minimal projection error (Jung 1964). Furthermore, local swelling of the sinus membrane and opacities can be diagnozed.

Additional information can be obtained with the help of specialized skull views (White & Pharoah 2000). The occipito-mental or Water's projection is optimal for visualization of the paranasal sinuses including the maxillary sinuses. Taken at varying angles (15°, 30° and 35°) a comparison of internal anatomy, bony continuity and defects, as well as sinus pathology or foreign objects is possible (Gonty 1994). Other images that may be included are the submentovertex, posteroanterior and lateral skull views. The lateral skull view allows examination of all four pairs of paranasal sinuses, but with each member of a pair superimposed on the other.

Computerized tomography (CT) and magnetic resonance imageing (MRI) have become increasingly important for the evaluation of sinus disease and have virtually replaced conventional tomography (White & Pharoah 2000). These modalities provide multiple sections through the sinuses at different planes and therefore contribute to the final diagnosis and the determination of the extent of the disease. High-resolution axial and coronal CT and MRI examinations are the most revealing noninvasive techniques for the paranasal sinuses and adjacent structures and areas (Perez & Farman 1988, White & Pharoah 2000). Tomographic systems that have been developed specifically for oral surgical purposes facilitate three-dimensional evaluation of the sinus. Because coronal sections through dental fillings, crowns and metallic restorations can result in artefacts, axial sectioning is carried out. Considering the fact that the use of three-dimensional methods, such as conventional tomography and computed tomography, is almost compulsory for presurgical diagnosis in implant surgery, the use of these diagnostic techniques also seems to be justified in conservative dentistry (Tachibana & Matsumoto 1990).

A-mode ultrasound is a safe, quick, noninvasive technique that has been introduced as a diagnostic screening tool for sinus pathology (Landman 1986). The ultrasonic waves are generated by a probe that contains a piezoelectric crystal stimulated by an alternating current oscillator (Landman 1986). When applied to portions of human anatomy, these waves are transmitted, reflected

and scattered depending on the physical properties of the tissues. In normal sinus scans an initial reflected echo is seen at the probe/skin interface and the second echo at the bone/air interface. With mucosal thickening an echo will be obtained from the mucosa/air interface as well as the bone/mucosa interface. A back wall echo is obtained when fluid or a large polyp carries ultrasound to the posterior bony wall, which reflects an echo. The accuracy of ultrasound in detecting fluid has been well documented. Mann *et al.* (1977) compared A-scan results with sinus irrigations and found that 93% of cases with back wall echoes had fluid confirmed by irrigation. Revonta (1980) compared ultrasound with radiography in the detection of secretions in sinuses as confirmed by trephination or sinus puncture. In adults, ultrasound was 90% and radiography 82% accurate; in children ultrasound was 94% and radiography was 75% accurate in detecting fluid. Revonta & Suonpaa (1982) later showed that disappearance of ultrasonic signs of sinusitis correlated better with clinical resolution than did the disappearance of radiological signs. Ultrasound provides an excellent method of screening for sinus pathology at a cost about 25% that of conventional radiographs (Landman 1986) and may be helpful in following the resolution of acute suppurative sinusitis instead of repeated radiographs (Pinheiro *et al.* 1998). If the scan is abnormal, ultrasound is not a replacement for radiographic studies, which are necessary to differentiate fluid, polyps, thick mucosa or tumours (Landman 1986).

Diagnostic endoscopy (Kennedy *et al.* 1985, Kennedy 1985) allows direct optical evaluation of processes of unknown origin in the antral floor region. It is an optimal method especially for the assessment of foreign bodies (such as root filling materials and root tips) that have penetrated into the maxillary sinus. The following paths of access can be used: transoral access via the canine fossa, transalveolar access via an already existing connection between the oral cavity and the antrum (e.g. when the antrum is artificially exposed during apicectomy) and access via the inferior meatus of the nose.

The 30° and 70° endoscope has been used as an adjunct to endodontic surgery involving maxillary and mandibular molars (Held *et al.* 1996). This instrument has been found to allow visualization in previously inaccessible areas such as maxillary molar roots that are often positioned behind the distobuccal root of the maxillary first molar. In cases in which maxillary roots have been found to penetrate into the maxillary sinus, this instrument has aided the operator in identification and treatment of these diseased root apices following entry into the sinus (Held *et al.* 1996).

Differential diagnosis

Sinusitis can clinically be divided into acute, subacute and chronic. Symptoms associated with acute or subacute maxillary sinusitis can be mistaken for those of pulpal origin (Schwartz & Cohen 1992). A comprehensive review of the patient's medical and dental history will frequently alert the clinician to a recent upper respiratory tract infection, chronic rhinitis or a painful episode associated with an aeroplane flight. Although it is not known whether 'allergic sinusitis' can be distinguished as a specific entity, the relationship between allergy and sinusitis has been discussed for many years (Demoly *et al.* 1994). The chief complaint associated with maxillary sinusitis is dull pain, generally unilateral and during mastication, or a feeling of 'fullness' around the first molar-second premolar area. The patient may report that the pain is exacerbated when lying down or bending over owing to increased intracranial pressure from blood flow.

Clinical examination of the patient with suspected maxillary sinus disease should include extra-oral tapping of the anterior and lateral walls of the sinus over the prominence of the cheekbones and/or palpation intraorally on the lateral surface of the maxilla between the canine fossa and the zygomatic buttress. Some authorities recommend palpation of the posterior wall of the maxillary sinus as a very useful diagnostic test but this is not featured in the literature. The affected sinus may be markedly tender to tapping or palpation (Schow 1993). The teeth affected by sinusitis will be moderately or extremely sensitive to palpation and/or percussion, but will respond within normal limits to conventional pulp sensibility tests. Pain typically radiates to all the posterior teeth in the quadrant so that all the teeth usually become tender to percussion. The nasal passage on the affected side may be partially or completely blocked. Nasal discharge is considered to be a significant sign of sinus infection. Without a discharge, it is unlikely that a significant sinusitis exists. Severe acute or subacute sinusitis rarely produces a fever, but a severe fulminating sinusitis will produce a high temperature and some degree of malaise. If only one tooth demonstrates tenderness to percussion, one should suspect this as the source of trouble and discount sinusitis. It is often helpful to use transillumination of the sinus (Schow 1993). This is done by placing a bright flashlight or fibre-optic light against the mucosa on the palatal or facial surfaces of the sinus and observing the transmission of light through the sinus in a darkened room. Decreased transmission of light would suggest congestion of the sinus, usually with swelling or thickening of the mucosa. Fluid or pus might also be

present (Schow 1993). Decreased transillumination may also be owing to a hypoplastic or even a contracted sinus (Pinheiro *et al.* 1998). Radman (1983) suggested the placement of a cotton swab saturated with 5% lidocaine (lignocaine) in the nostril of the affected side as a differential diagnostic test. The swab is placed posteriorly to the area of the middle meatus and left in place for 20–30 s. If the pain is of sinus origin it will be modified or eliminated within 1–2 min and thus lead to the presumptive diagnosis of maxillary sinusitis. Similarly, the use of a topical nasal decongestant may help in differentiating pain from sinusitis vs. pain of dental origin, the assumption being that the pain is as a result of the pressure from the inflamed sinus tissue. Possible radiographic changes that may be seen in sinusitis are thickened sinus mucosal membrane, an air-fluid level or complete opacification (Pinheiro *et al.* 1998).

In contrast to pain of sinus origin, pain of dental origin is much more variable and ranges from thermal sensitivities to spontaneous episodes of sharp pain and unrelenting severe pain and may be associated with regional swelling and cellulitis. In advanced dental disease, radiographic evidence is usually apparent. Negative responses to routine pulp tests are helpful in finding a dental source of disease, whereas normal responses might aid in eliminating possible dental foci and in establishing a diagnosis of sinusitis.

Periapical infections (Endo–antral syndrome)

The direct extension of dental sepsis into the sinus was shown for the first time in a study by Bauer (1943). His study was performed on cadavers and showed examples of pulpally involved teeth with histologically evident extension of disease into the maxillary sinus. These examples ruled out generalized sinus disease and clearly implicated the infected teeth. Microscopically, the 'diseased areas' showed the destruction of the bone separating the sinus from the teeth, with particular loss of the cortical bone normally found on the sinus floor. In addition, the sinus mucosa was seriously altered in many ways such as swelling with inflammation, granulation tissue, hypertrophy, fibrous changes, hyalinization or complete necrosis. The pathological disruption of both periapical and adjacent sinus tissue resulting from endodontic infection has since been well documented (Selden & August 1970, Selden 1974, Selden 1977, Selden 1989). The reported frequency of sinusitis of dental origin varied considerably, between 4.6 and 47% (Mélen *et al.* 1986) of all sinusitis cases. The spread of pulpal disease beyond the confines of the dental supporting tissues into the maxillary sinus was termed Endo–antral syndrome (EAS) by Selden (1974), Selden (1989) and Selden (1999). It has been shown that the closer the apex of a pulpally involved tooth is to the floor of the sinus, the more likely and the greater the impact will be on the sinus tissues (Matilla 1965). According to Bauer (1943), periapical infection spreads through the bone marrow, following the path of blood vessels and lymphatics. If pulpal disease develops slowly, as in chronic inflammation with no significant infection, then the spread to the sinus can be slow with minimal impact. Acute infectious pulpal disease is much more destructive and rapidly spreading, capable of significantly involving the adjacent sinus within a short time. Reports in the literature of the rapid spread of dental infections through the maxillary sinus and subsequent periorbital cellulitis, blindness and even life-threatening cavernous sinus thrombosis (Albin *et al.* 1979, Gold & Sager 1974, Jarrett & Gutman 1969, Pellegrino 1980, Robbins & Tarshis 1981) exemplify the serious potential complications of EAS. The findings that characterize EAS are: (i) pulpal disease in a tooth whose apex approximates the floor of the maxillary sinus; (ii) periapical radiolucencies on pulpally involved teeth; (iii) radiographic loss of the lamina dura defining the inferior border of the maxillary sinus over the pulpally involved tooth; (iv) a faintly radiopaque mass bulging into the sinus space above the apex of the involved tooth, connected neither to the tooth nor the lamina dura of the tooth socket (representing a localized swelling and thickening of the sinus mucosa); and (v) varying degrees of radiopacity of the surrounding sinus space (comparison of the contralateral sinus is often helpful) (Selden 1999). The variable presentation of EAS can create diagnostic and therapeutic difficulties, because cases do not always show all five features.

Sinus mucosal hyperplasia is present in approximately 80% of teeth with periapical osteitis (Matilla 1965, Matilla & Altonen 1968). Microscopically, other changes in the sinus mucosa, such as swelling, cyst formation, hypertrophy and even transformation of the mucosa to granulation tissue can be seen (Bauer 1943). In the past these mucosal changes in the sinus led to the belief that the involved teeth should be extracted (Bauer 1943). The belief was reinforced by the study of Ericson & Welander (1966) who found that inflammatory reactions occur in the lateral wall of the sinus as a result of periapical osteitis and disappear after the extraction of the affected teeth. In 1967, Nenzen & Welander performed a study on 24 patients with periapical lesions of which 14 (58%) displayed local hyperplasia of the sinus mucosa. Seven of these 14 cases received conventional endodontic

treatment and all seven showed regression of the mucosal hyperplasia. The control group (who did not receive endodontic treatment) showed regression in only one case. The results indicated that conservative root canal therapy could eliminate local hyperplasia of dental origin in the mucosa of the maxillary sinus. Selden & August (1970) also managed to retain teeth and attain resolution of sinusitis after treatment of a periodontal-endodontic lesion involving first and second premolars. These studies seem to indicate that most cases of EAS will respond satisfactorily to nonsurgical root canal treatment. For those cases refractory to routine conservative management, a surgical approach was recommended (Selden & August 1970, Selden 1989).

Conventional endodontic treatment

The maxillary sinus poses a special challenge when root canal treatment is performed on teeth with roots in close proximity to the maxillary sinus. Although it is well established that all endodontic instruments and materials should be restricted to the confines of the root canal system during treatment, procedural errors are common and part of every day practice. It frequently happens that instruments and medicaments are introduced beyond the apical foramen (Dodd *et al.* 1984, Fava 1993, Kaplowitz 1985, Kobayashi 1995). In addition, some degree of inflammatory response normally occurs after root canal preparation even when all instrumentation is kept within the canal. If the root apices are in close proximity to the maxillary sinus, then the inflammatory response may involve the sinus mucosa.

Results from several studies (Engström & Spångberg 1967, Seltzer *et al.* 1968, Seltzer *et al.* 1969) showed that for optimal repair in cases of vital pulp extirpation, instrumentation should be confined to the root canal. An inflammatory reaction normally occurs in the periapical tissues after pulp extirpation (Seltzer 1988). Despite strict control of working length during root canal preparation, extrusion of debris into the periapical tissues may occur, causing periapical inflammation, postoperative pain and possibly delayed healing (Fairbourn *et al.* 1987, McKendry 1990). When the periapical tissues are severely damaged by overzealous reaming or filing, the consequent inflammatory response is more severe (Seltzer *et al.* 1968). Mechanical injury to the periapical tissues is likely to initiate the release of non-specific mediators of inflammation. In addition, the continued release of antigens from an inflamed pulp or infected root canal into the periapical tissues (Engström *et al.* 1964) can result in various types of immunologic reactions. This is especially true for pulpless teeth with associated periradicular lesions (Baumgartner & Falkler 1991, Fukushima *et al.* 1990, Sundqvist *et al.* 1989, Yoshida *et al.* 1987). It is speculated that inadvertent inoculation of the infectious contents from the root canal predisposes the pulpless tooth to peripical exacerbation (Fukushima *et al.* 1990, Harrington & Natkin 1992). Additional periapical injury may be induced by the use of certain medicaments and still further irritation by root canal fillings, especially when they impinge on the periapical tissues (Bergenholtz *et al.* 1979). Thus, a compounding of irritation may occur during the sequence of normal endodontic procedures (Seltzer 1988). The irritation may be so severe that the defence resources of the periapical tissues cannot overcome it. A granuloma may thus persist in the periapical tissues after completion of root canal treatment. Should epithelial cell rests begin to proliferate, a cyst may form.

The inadvertent injection of sodium hypochlorite (NaOCl) into the periapical tissues may impact on the maxillary sinus (Ehrich *et al.* 1993, Kavanagh & Taylor 1998). Pashley *et al.* (1985) found that NaOCl elicited severe inflammatory reactions and was extremely toxic to all cells except heavily keratinized epithelia. Sodium hypochlorite solution is a commonly employed root canal irrigant, and there have been numerous reports of soft tissue complications as a result of its inadvertent injection beyond the confines of the tooth (Becker *et al.* 1974, Becking 1991, Cymbler & Ardakani 1994, Ehrich *et al.* 1993, Gatot *et al.* 1991, Harris 1971, Herrmann & Heicht 1979, Kavanagh & Taylor 1998, Reeh & Messer 1989, Sabala & Powell 1989). The immediate sequelae of these accidents include severe pain, oedema and profuse haemorrhage both interstitially and through the tooth. Several days of increasing oedema and ecchymosis occur, accompanied by tissue necrosis, paraesthesia and sometimes, secondary infection. The majority of cases showed complete resolution within a couple of weeks whilst a few have been marked by long-term paraesthesia or scarring (Gatot *et al.* 1991, Reeh & Messer 1989). Two cases of inadvertent injection of NaOCl into the maxillary sinus have been reported (Ehrich *et al.* 1993, Kavanagh & Taylor 1998). Ehrich *et al.* (1993) reported a case of endodontic therapy of a maxillary right first molar. Shortly after irrigation of the palatal canal with 5.25% NaOCl the patient complained about a taste in his throat despite the presence of an effective rubber dam. On irrigation of the canal with sterile water it was found that the water passed through the palatal canal into the maxillary sinus, into the nasal cavity via the ostium and thence into the pharynx. Apart from an initial congestion and mild

burning sensation in the right maxilla the patient experienced no severe consequences and was asymptomatic 4 days after the incident. The second case (Kavanagh & Taylor 1998) involved a maxillary right second premolar. The patient experienced acute severe facial pain and swelling during irrigation with NaOCl solution. An attempt to drain the sinus through reopening the access cavity was unsuccessful and it was surgically drained by a Caldwell–Luc approach. Despite an apparent healing of the sinusitis, the tooth remained painful and was extracted 3 months after the initial presentation.

Intracanal medicaments placed between visits may inadvertently be extruded into the sinus. The use of calcium hydroxide ($Ca(OH)_2$) paste as an interappointment dressing is common (Byström *et al.* 1985, Fava 1992, Heithersay 1975). $Ca(OH)_2$ is irritating to tissue and has an immediate degenerative effect upon cells (Kawahara *et al.* 1968), before the material is removed by macrophages or foreign body giant cells. Until such removal is complete, total repair with an absence of inflammation does not occur. Haanæs *et al.* (1987) injected $Ca(OH)_2$ into the maxillary sinus cavity of monkeys to evaluate its clinical, radiological and histological effect on the sinus mucosa. Results from this study clearly show that sinusitis can occur when $Ca(OH)_2$ is deposited into the sinus. The authors ascribed the inflammatory response of the sinus mucosa to the material initially acting as a chemical irritant and later as a foreign body. They also considered the amount deposited into the sinus as important to the inflammatory response. A few cases of $Ca(OH)_2$ extrusion into the maxillary sinus have been reported in the literature (Engström & Ericson 1964, Fava 1993, Marais 1996). Despite the reported effects of $Ca(OH)_2$ on the tissues, these cases have showed spontaneous healing.

During obturation, the sinus may be invaded by either sealer or by solid materials such as gutta percha or silver cones. Mechanical irritation results from overfilling the root canal, thereby impinging foreign materials on the vital tissues. The material produces an inflammatory reaction with an area of rarefaction in the periapical tissues. Such inflammation is likely to persist until the foreign object is removed. Many sealers have been reported to cause paraesthesia if extruded into the mandibular canal or the mental foramen (Fava 1993). Amongst the sealers that cause paraesthesia when in direct contact with the inferior alveolar nerve are: N2 (Grossman 1978, Orlay 1966), AH26 (Tamse *et al.* 1982), Endomethasone (Forman & Rood 1977, Kaufman & Rosenberg 1980, Ørstavik *et al.* 1983), Spad (Foreman 1982) and Hydron (Pyner 1980). Brodin *et al.* (1982) and Brodin & Ørstavik (1983) have documented the particularly strong and irreversible neurotoxic activity of the root filling materials N2 and Endomethasone, but indicated that other materials, including formulations like Kloroperka N-Ø, zinc oxide-eugenol and AH26 also displayed some neurotoxicity. The paraesthesia may be caused by direct pressure of the material over the neurovascular bundle or by a neurotoxic affect on the nerve trunk (Rowe 1983). There have been very few reports concerning sealer extrusion into the maxillary sinus. Orlay (1966) reported a case where N2 had been extruded into the maxillary sinus. The patient complained about severe pain radiating across the trigeminal region. After removal of part of the lateral wall of the sinus and irrigation of the sinus to remove a ball of N2, the area healed and the pain did not return. Block *et al.* (1980) found ^{14}C-labelled paraformaldehyde in blood, regional lymph nodes, kidney and liver after insertion of N2 paste into the root canals of dogs' teeth after instrumentation of the canals 1–1.5 mm short of the radiographic apex. They concluded that paraformaldehyde should not be incorporated in any root canal sealer. The same concern was reflected in the guidelines for root canal treatment of the British Endodontic Society (1983), which stated that cements containing paraformaldehyde, with or without corticosteroids, were unacceptable. The use of these sealers in teeth with roots in close proximity to the sinus is thus strongly contraindicated.

Root filling materials have also been reported as causative agents of maxillary sinus aspergillosis (Beck-Mannagetta & Necek 1986, De Foer *et al.* 1990, Krennmair & Lenglinger 1995). Kopp *et al.* (1985) and Stammberger *et al.* (1984) found that the typical radiopaque maxillary sinus concretions seen in more than 50% of the cases with diagnozed sinus aspergillosis were iatrogenically placed endodontic materials. These findings were confirmed in a study by Legent *et al.* (1989), who reported that 85% of 85 reported cases of aspergillosis of the maxillary sinus were related to overextended root canal sealer in maxillary teeth. Stammberger *et al.* (1984) and Kopp *et al.* (1985) described the influence of root-filling materials containing zinc oxide-eugenol on the pathogenesis of sinus aspergillosis, confirming the microbiological findings of Ross (1975) who demonstrated that *Aspergillus fumigatus* needs heavy metals such as zinc oxide for proliferation and metabolism. According to this 'dental' hypothesis, sinus aspergillosis is caused by overfilling of the root canal, with the zinc oxide in the root filling material inducing the infection. However, Odell & Pertl (1995) found that zinc oxide eugenol sealers showed antifungal activity against *Aspergillus*. In addition to the hypothesis of *Aspergillus* spore-induced zinc oxide metabolism, sinus aspergillosis may also be owing to nonremovable heavy

metal foreign bodies situated within an altered soft tissue and additional spore inhalation. By paralysing the cilia or by inducing soft tissue hypervascularization and oedema, these trace elements may cause an alteration of the respiratory epithelium (Hybbinette & Mercke 1982, Reinhold 1975), the heavy metal concretions thus becoming a hiding place for spores that cannot be removed by the respiratory epithelium. Therefore, it appears as though the dental origin of sinus concretions can be explained not only by the metabolic effect of zinc oxide but also by the 'inorganic mass' itself as it has a heavy texture and is difficult for the respiratory epithelium to remove. According to the findings of Krennmair & Lenglinger (1995), the use of zinc oxide-containing root canal filling materials can be considered a risk factor and may have a promoting effect on the pathogenesis of sinus aspergillosis. Kobayashi (1995) reported a case of a patient with asymptomatic sinus aspergillosis developing around a foreign body. Inductively coupled mass spectrometry (ICP) revealed that the foreign body corresponded to gutta-percha, with zinc, sulphur and calcium the principal elements present. Khongkhunthian & Reichart (2001) reported two cases of sinus aspergillomas related to overextended root canal material in maxillary first molars. They suggested that all overextended root canal filling materials in the maxillary sinus should be removed to prevent the development of aspergillosis infection. Aspergillosis can be divided into noninvasive, invasive and allergic variants (Khongkhunthian & Reichart 2001). The invasive form is usually associated with immunocompromised patients. The noninvasive and allergic forms result in obstruction and a chronic sinusitis. These forms do not respond to conventional medical management and the suggested treatment is surgical removal of the fungal masses. *In vitro* and *in vivo* data showed that zinc oxide eugenol containing sealers, especially those which release paraformaldehyde, should not be applied for the filling of root canals of upper posterior teeth (Geurtsen 2001).

Sjögren *et al.* (1995) showed in their study that gutta percha evoked two distinct types of tissue response and that the size and surface character of the material determined the type of tissue reaction. Large pieces were well encapsulated and the surrounding tissue was free of inflammation, whilst fine particles of gutta-percha evoked an intense, localized tissue response, characterized by the presence of macrophages and multinucleated giant cells. In a further study by Sjögren *et al.* (1998) it was found that mouse peritoneal macrophages, when exposed to gutta percha particles, released factors which have bone resorbing activity. Kaplowitz (1985) reported two cases with penetration of the maxillary sinus by gutta percha cones extending through the palatal root of maxillary first molars. In one case this caused a chronic maxillary sinusitis, which persisted for 1 year. The condition was finally resolved by the extraction of the tooth and the administration of an antihistamine. In the other case, no complications were noted.

Dodd *et al.* (1984) reported a case in which a maxillary first molar was overfilled with silver cones, resulting in chronic sinusitis. The aetiology was initially undiagnozed and the patient was subjected to unnecessary surgery of the sinus. Endodontic retreatment of the case eliminated the patient's symptoms and returned the tooth to a state of health and function. Corrosion is a well known property of silver points and can also be a potential hazard in cases where the silver point is overextended. Seltzer *et al.* (1972) found that silver points contacting tissue fluids became corroded with the formation of silver sulphide, silver sulphate and silver carbonate. These corrosion products are known to be cytotoxic and silver cones pushed beyond the apex of the tooth are severely toxic to the periapical tissue (Seltzer *et al.* 1972).

Endodontic surgery

Endodontic surgery in anterior teeth is usually carried out without hesitation, whereas in the posterior regions extraction is sometimes preferred. Amongst the reasons for extraction are the clinician's lack of experience, the close proximity to the inferior alveolar nerve in the mandible and the extremely close relationship between the apices of the premolar and especially the molar teeth and the floor of the maxillary sinus in the maxilla (Gutmann & Harrison 1985, Skoglund *et al.* 1983). Oroantral communications may not necessarily be an iatrogenic event (Jerome & Hill 1995). Pathological exposure of the sinus floor predisposes many surgical endodontic procedures to maxillary sinus communication (Selden 1989). Additionally, endoantral lesions may not always be radiographically evident preoperatively (Jerome & Hill 1995).

The thickness of bone separating the apices of the teeth in the lateral segments of the maxilla from the sinus is shown to be in the range of 0.8–7 mm (Eberhardt *et al.* 1992). Perforations of the maxillary sinus following apicectomy of premolar and molar teeth in the maxilla have been reported by Ericson *et al.* (1974), Ioannides & Borstlap (1983), Rud & Rud (1998) and Freedman & Horowitz (1999). Ericson *et al.* (1974) found perforations in 18% of 159 premolar and molar apicectomies. Ioannides & Borstlap (1983) found 14.8% perforations from 47 maxillary molar apicectomies, Rud & Rud (1998) found 50% perforations in 200 cases of root resection of

first maxillary molars and Freedman & Horowitz (1999) reported 10.4% perforations following 472 apicectomies on premolar and molar teeth.

The relative positions of the roots to the sinus are reported in several studies (Eberhardt *et al.* 1992, Killey & Kay 1967, Norman & Craig 1971, Von Wowern 1971). Killey & Kay (1967), quoting the results of anthropological studies by Von Bonsdorff (1925) reported the frequency of close proximity (0.5 mm or less) of roots of posterior maxillary teeth to the sinus floor: second molars 45.5%, first molars 30.4%, second premolars 19.7% and first premolars 0%. The distribution of oroantral communications amongst different groups of teeth in the studies by Ericson *et al.* (1974) and Freedman & Horowitz (1999) agreed well with their close proximity to the sinus floor reported by Killey & Kay (1967). Ericson *et al.* (1974) found oroantral communications in 7.7% of canines, 8.8% of first premolars, 26.1% of second premolars and 40% in molars, whilst Freedman & Horowitz (1999) found 23% perforations in molars, 13% in second premolars and 2% in first premolars.

Invasion of the maxillary sinus does not seem to result in permanent alteration of either the sinus membrane or its physiological function. Selden (1974) as well as Benninger *et al.* (1989) observed that the mucous membrane, complete with cilia, regenerate in about five months after total surgical removal. There is also agreement that the sinus membrane will recover from sinusitis once proper ventilation is restored (Stammberger 1986).

After apicectomy there will often be sinus mucosal thickening and signs of sinusitis that may either be attributed to the introduction of foreign material into the sinus at the time of operation or to persistent periapical infection (Ericson & Welander 1964, Ericson & Welander 1966, Ericson *et al.* 1974). It is thus of utmost importance that a meticulous technique be used to ensure that foreign material or the resected tooth apex does not enter the sinus (Jerome & Hill 1995, Lin *et al.* 1985). Attempting to retrieve root tips, ground dentine and gutta percha debris from the sinus after apicectomy is difficult because of limited access and may cause additional unnecessary trauma (Jerome & Hill 1995). Since virtually all roots requiring apicectomy are associated with endodontic failures and/or periapical inflammatory lesions, their exclusion from the sinus is imperative. The buccal roots of upper posterior teeth in close proximity to the sinus can nearly always be treated without risk of perforation of the sinus. Barnes (1991) suggested cutting through bone and approaching the root from the front and below, never from above. He also suggested burring down of the apical part of the root to the desired level rather than resection owing to the risk of displacement of the resected tip into the sinus. However, in the presence of an existing sinus exposure, grinding the root to the desired level may create more debris than a single sectional cut and inflammatory tissue can be lost into the sinus during curettage (Jerome & Hill 1995). Jerome & Hill (1995) described a method by which a hole is drilled in the root apex to secure the root tip with a suture before apicectomy, thus enabling the removal of the inflammatory lesion with the root tip. If a root tip is displaced into the maxillary sinus further management will be required as the likelihood of the foreign material being infected is high. A post complication radiograph is mandatory to identify and locate the object. Further management may include referral to a surgical specialist.

Repair of the bony partition between sinus and apex after root canal treatment or surgery will usually occur (Ericson *et al.* 1974). Ericson *et al.* (1974) found that only four out of 26 patients examined in their tomographic study did not show bony repair after apicectomy. In three of these cases periapical radiographs showed successful healing whilst the fourth case was classified as uncertain healing. These results indicate that in a small percentage of patients with sinus perforations bony healing may not occur following apicectomy, but it may not necessarily affect the healing of the sinus mucosa (Freedman & Horowitz 1999).

Watzek *et al.* (1997) found no significant difference in the healing rate between patients with and without intraoperative sinus exposure in 146 apicectomies. These findings were consistent with those of Ericson *et al.* (1974), who showed no difference between the results regarding treatment outcome of apicectomies obtained in the groups without and those with oroantral communications. In the same study the results of the operation in the oroantral communication group with ruptured sinus mucosa did not differ from those in the group with intact mucosa. Surgical treatment of maxillary teeth with periapical periodontitis refractory to conventional endodontic treatment is thus recommended, regardless of the anatomical relationship of the teeth to the maxillary sinus.

Jerome (1994) reported an unusual and rare case with a horizontal root fracture of the mesiobuccal root of a maxillary first molar. The source of the fracture was determined to be trauma from access or curettage during two Caldwell–Luc maxillary sinus procedures. This case points out the necessity to take a good medical and dental history and emphasizes the fact that sinus surgery itself may have endodontic implications.

Many clinicians have used stabilisers (endosseous endodontic implants) as an adjunct to dental treatment over the last few decades (Feldman & Feldman 1992,

Frank 1967, Orlay 1964). Endodontic stabilisers are indicated in both anterior and posterior teeth when a more desirable crown/root ratio is needed to increase stability (Feldman & Feldman 1992). According to Feldman & Feldman (1992) certain anatomical structures should be considered during the planning of treatment. Although they stated that penetration into the sinus does not supply additional stability, they showed a case with sinus perforation with a stabiliser in a maxillary molar one year postoperatively with apparently no need for splinting. Benenati (1989) reported a case where a sapphire endodontic stabiliser in a canine tooth perforated the maxillary sinus. The patient complained of periodic foul smelling purulent drainage from her right nostril and occasional swelling of her right cheek. Because of its limited degree of radiopacity, the implant was not readily identifiable on the preoperative radiograph and at operation could only be resected using a diamond bur.

In some instances broken instruments and/or filling materials in the maxillary sinus can only be removed by means of a Caldwell–Luc procedure (Bailey 1998, Bjørnland *et al.* 1987, Kobayashi 1995). The history of the Caldwell–Luc operation dates back to the last decade of the 19th century when Henri Luc of France and George Caldwell of the United States independently described the principle of eradicating disease from the sinus and providing counterdrainage into the nose (Macbeth 1971).

An incision is made either around the necks of the teeth or in the buccogingival sulcus approximately 2 mm above the mucogingingival junction extending from the canine eminence to the posterior maxilla. A releasing incision is usually performed to prevent trauma to the mucoperiosteal flap during elevation. The soft tissues are elevated superiorly in the subperiosteal plane to expose the lateral maxillary wall. The infraorbital nerve is identified and carefully protected. An opening into the sinus is created through the canine fossa region above the roots of the maxillary teeth or it may be created more posteriorly depending on the pathologic condition. Sinus mucosa removal is dictated by the extent of disease with healthy mucosa being preserved. If the sinus disease is severe, a naso-antral window may be created transantrally into the inferior meatus to establish dependent drainage (Bailey 1998, Gonty 1994).

The palatal root of molars

The palatal roots of maxillary molars pose a special problem during endodontic surgery procedures. These roots are 50% closer to the sinus than they are to the palate (Wallace 1996), show apical communication with the sinus 20% of the time and are less than 0.5 mm from the sinus 40% of the time (Watzek *et al.* 1997). A deep palate offers long vertical lateral walls and improved access. A shallow palate not only presents visibility, incision and elevation difficulties, but palatal root access is further complicated by the proximity of the apices to the greater palatine vessels (Arens *et al.* 1998). A major concern with any palatal flap is its reapproximation and reattachment following surgery. The pooling of blood between the flap tissue and the bone may cause gravitational sag with ischaemia and sloughing (Arens 1998). Together with other difficulties such as limited opening, a flat or thick palatal vault, the proximity to major vessels and nerves and the fact that the palatal root of the maxillary first molar is the most common root displaced into the sinus, the transantral approach may be seen as a desirable option (Wallace 1996). This technique has been described and successfully used by several authors (Altonen 1975, Rud & Andreasen 1972, Wallace 1996). It involves the raising of a full mucoperiosteal flap, resection of the two buccal roots, followed by opening of the lateral wall of the sinus with a large bone bur (Altonen 1975). Drilling is discontinued as soon as the bluish periosteum of the sinus appears. The periosteum is carefully loosened from the edges of the opening, using a curved periosteal elevator. The opening is widened with a rongeur to a size of about 1×1.5 cm (Altonen 1975, Wallace 1996). The periosteum is loosened from the base of the sinus with a curved elevator and the palatal root tip is exposed, by removing the paper thin bone layer from its top with a concave chisel. The root is resected at the desired level, the root end is prepared with an ultrasonic retrotip and a root end filling is placed (Wallace 1996). Compared with the Caldwell–Luc procedure for sinusitis, which involves a large bony opening and a radical removal of the antral lining, the insult of sinus exposure from this form of endodontic surgery is relatively minor (Wallace 1996). Despite the favourable arguments for the transantral approach, potential complications cannot be overlooked (Wallace 1996). The most obvious concerns would be development of an oroantral communication or chronic sinusitis after surgery. Proper technique, careful manipulation of tissue and the recommended antibiotics and decongestants should minimize these complications (Altonen 1975, McGowan *et al.* 1993).

Antibiotics, decongestants and analgesics in the management of sinusitis

At least 70% of bacterial complications of acute sinusitis are caused by *Streptococcus pneumoniae* and *Haemophilus*

influenzae, of which some 20–30% produce β-lactamase (Yonkers 1992). Several other bacterial species, including *Moraxella (Branhamella) catarrhalis*, *Streptococcus pyogenes*, *Staphylococcus aureus*, and α-streptococci, account for a proportion of cases. Approximately 10% of cases of acute sinusitis in adults arise from dental infections containing a mixture of anaerobic species (Gwaltney 1995). Antibiotics are a fundamental part of management in acute suppurative sinusitis. Pinheiro *et al*. (1998) recommended amoxycillin as a first-line empiric therapy aimed at covering both Gram-positive and Gram-negative organisms. Amoxycillin and its derivatives also cover Gram-negative encapsulated organisms such as *H. influenzae* and *S. pneumoniae*, making it particularly useful in the medical management of sinus disease. Other acceptable and inexpensive choices for first line therapy would be a combination of erythromycin and a sulphonamide or a second generation cephalosporin and a sulphonamide. However, patients with true hypersensitivity reactions to penicillin should not be given cephalosporins owing to cross-reactivity in approximately 10% of the population. In these patients, cotrimoxazole or clarithromycin may be suitable alternatives.

Synthetic penicillin antibiotics with a β-lactamase inhibitor (e.g. amoxycillin-clavulanate) have a broader spectrum of activity against β-lactamase producing strains of *Haemophilus influenza* and *Moraxella catarrhalis*, but they may not be effective against penicillin resistant pneumococcus. Second generation cephalosporins also cover β-lactamase producing organisms. Individuals who have failed prior antibiotic treatment or with a history of frequent episodes recalcitrant to amoxycillin treatment may require a different antibiotic or a combination of antibiotics before a more invasive option is explored.

Intravenous antibiotics may be indicated in individuals with severe infections involving other sites, such as the orbit or intracranial spread. Either second or third generation cephalosporins or ampicillin sulbactam are good choices owing to excellent penetration of the blood–brain barrier in addition to covering the relevant organisms. Anaerobic coverage can be provided by metronidazole, which also has good penetration of cerebrospinal fluid.

Clinical improvement usually occurs within 48–72 h of initiation of antimicrobial therapy. The antibiotic-therapy should be continued for a minimum period of 7 days after the symptoms have disappeared. Treatment for lesser periods of time may cause relapse or the disease may progress to chronic sinusitis. Smith & Browning (2000) suggested that general dental practitioners should not prescribe antibiotics for uncomplicated acute sinusitis. For patients presenting with symptoms of maxillary toothache, dental practitioners are best placed to examine the oral cavity for prompt treatment of dental disease. Cases that do not resolve should be referred once dental disease has been excluded as a source of infection.

The combination of allergic disease and infectious sinusitis has been considered the most difficult form of sinus disease to treat (Shin & Bellenir 1998). The patient with uncontrolled nasal allergies frequently experiences marked congestion, swelling, excess secretions and discomfort in the sinus area. These patients need to follow an allergy care programme to alleviate sinusitis.

In addition to destroying the involved organisms, it is important to decrease oedema around the ostia to facilitate drainage and allow sinus oxygenation (Pinheiro *et al*. 1998). Topical and systemic decongestants are beneficial and facilitate oxygenation and sinus drainage of pus by decreasing the ostial mucosal oedema. This is one of the few instances in which topical decongestants, drops or sprays are advocated and are beneficial, provided that their use is not extended beyond 3–5 days as a result of significant rebound effect.

Analgesics, such as paracetamol and nonsteroidal anti inflammatory drugs, are important for the control of pain. However, in severe sinus pain cases, a narcotic analgesic may be indicated.

Conclusion

The close anatomical relationship of the maxillary sinus and the roots of maxillary molars, premolars and in some instances canines, can lead to several endodontic complications. Periapical periodontitis may result in maxillary sinusitis of dental origin with resultant inflammation and thickening of the mucosal lining of the sinus in areas adjacent to the involved teeth. In cases of sinusitis of dental origin conventional endodontic treatment or retreatment is the treatment of choice, with surgical intervention only indicated in refractory cases. Conventional root canal treatment may result in the perforation of the sinus floor in one or more of the stages of treatment with resultant irritation and inflammation of the maxillary sinus mucosa. This inflammation may be owing to overinstrumentation and/or inadvertent injection or extrusion of irrigants, intracanal medicaments, sealers or solid obturation materials. Furthermore, endodontic surgery performed on maxillary teeth may result in sinus perforation. Perforation caused during endodontic surgery constitutes a low risk to the maxillary sinus in the presence of a good knowledge of the specific anatomic

conditions, an adequate diagnosis and an appropriate surgical procedure. Root ends and/or materials may enter the sinus during conventional or surgical endodontic therapy with the need for a subsequent Caldwell–Luc approach. Antibiotics, decongestants and analgesics are indicated for the treatment of sinusitis or when the sinus is penetrated during surgical endodontic procedures.

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